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Procedure and Structure for an Instructional Laboratory Which Supplements Research

R. S. Adams Jr.
University of Minnesota

Procedure and Structure for an Instructional Laboratory Which Supplements Research

R. S. ADAMS, JR.*

ABSTRACT — This paper describes the organization of a laboratory course in Soil Chemical Analysis. Students select and pursue small research problems to gain experience in the soil analyses that are discussed in lecture and required in the laboratory. Involvement of the class in an actual research problem proved challenging to both the instructor and the class. The data obtained often supplemented current departmental research. Individual projects were found to be easier to supervise than team problems. This paper reports results of a team project examining parameters of a pot experiment. Shape of the pot, methods of watering, methods of fertilizing, and some chemical changes in the potted soil were studied. Two plant species — oats and soybeans — were used. Subirrigated pots gave the greatest yield of dry matter, but reducing conditions were produced that might not be desirable in some experiments. Addition of fertilizer at four-day intervals rather than by mixing it with the soil at the outset improved utilization of nitrogen, phosphorus and potassium but did not increase dry matter yield appreciably.

Although research programs and good teaching often have been thought incompatible, research can play an essential role in an effective teaching program. The professor involved in research becomes acquainted quickly with new discoveries or techniques and may be able to incorporate these into his instruction sooner than the faculty member who is involved only in teaching. Furthermore, a professor involved in current research usually has greater experience, more modern equipment, and better financial support. Certainly, effective graduate student training requires active participation in research by graduate instructors.

Today's science-oriented university graduate has an excellent background in the fundamentals of basic science. But if his program has not included some advanced laboratory courses, he may lack experience in applying knowledge to a particular problem and/or in reporting the results of a laboratory experiment effectively.

This paper has three objectives relating to the above ideas. The first is to describe how one laboratory course was designed to give students an opportunity to apply basic knowledge to a research problem while learning new laboratory techniques. The second is to show that a research program can profit from this kind of a teaching approach. The third is to illustrate the kind of research data that may be obtained from an instructional laboratory.

Laboratory Instruction Personalized

Most science departments have courses requiring students to pursue an individual problem either in the laboratory or the library. Nearly all offer one or more laboratory courses designed for future professionals in the discipline.

I have taught one such course over the past four years: a laboratory in Soil Analytical Chemistry Techniques. Because a new approach in laboratory teaching was being sought, the course has undergone continuous evolution. Less desirable experiments were abandoned and new ones introduced.

In the beginning the course was designed with four required exercises and two optional exercises. In the required exercises not more than two students did the experiment the same way. For example, in determinations of soil nitrogen, different digestion techniques, catalysts or methods were employed in an attempt to illustrate the advantages and disadvantages of various procedures. All data were pooled from each exercise, and reports were prepared from these data. The optional exercises were to be comprised of experiments designed by the student, but using specific analytical tools. At the conclusion of each experiment, the student was required to submit a written report and defend it orally before the class. Grades were assigned on the basis of a considered judgment of the students' interpretation and presentation of the data in the written and oral reports. Justification for this type of grading was based on the presumption that the best data a researcher may obtain is no better than his interpretation of it, or his ability to present the results to his peers. Recognizing the greater demands placed upon research equipment and on the instructor's time by this method, the course enrollment has been limited to ten students per quarter.

The assigned experiments, following traditional methods and usually leading to known results, seemed to have little advantage over a set of completely optional experiments.

In the optional work a deliberate effort was made to avoid imposing upon students the experiment to be pursued. However, suggestions were offered upon request, and examples of possible experiments were listed at the beginning of the course. This flexibility and diffidence to individual initiative made excessive demands on a few students, who did not do well in the course and would not be expected to do well in research careers. Almost all students were awed by the responsibility of selecting a research problem, but as they moved into chosen optional study, their enthusiasm grew. Reactions to the course were generally favorable, and some students asked or volunteered to continue work on their projects follow-

* Associate Professor, Soil Science, University of Minnesota; B.S. and M.S., Kansas State University; Ph.D., University of Illinois.

ing completion of the course. In general, students appeared to work harder, be more careful in their analyses, and delve more deeply into the literature when doing optional experiments than when doing assigned experiments.

To the instructor, however, the optional experiments may present at least two disadvantages. First, he must be prepared at times for technical questions that he may not be able to answer without assistance from fellow staff members. In addition, the instructor will find it impossible to anticipate all chemicals and supplies necessary for work on optional problems.

Individual optional experiments have one very important advantage. Through oral reports and class discussions, the class becomes exposed to many more techniques used in soil chemical analyses than would be possible in a laboratory course using conventional assignments.

Divisions in Team Study

The 1967 class chose to do a team study in which each student was responsible for some part of a broad experiment. Since, in the problem selected, no chromatographic analyses could be conveniently structured, each student was required to do an optional experiment using some form of chromatography. The two approaches could then be compared in the same quarter.

Results from the team approach were gratifying, but some factors which may make it an undesirable instructional tool appeared. Where experiments by some students may be dependent upon results obtained in experiments by others, some students may be penalized for failures which are not their own.

The team approach also restricted each student's flexibility to work on his problem and proved less stimulating than purely optional experiments. Finally, the team problem was much more difficult to control and direct than were the several individual options. Despite these shortcomings results from the team problem are reported here as an example of the kinds of basic information that can be obtained in an instructional laboratory.

Student Experiments Contribute to the Field

In the course described, students frequently pursued an optional experiment related to current research in the department. My research laboratory's function is the study of the persistence of pesticide residues in soils. Much of the chromatographic equipment in the department has been equipped to support this research. Frequently, chromatography experiments have related to soil pesticide residues. The students' class efforts have contributed to current research, initiated new research, and defined limitations of analytical techniques. The problem of one student, M. A. Turner, proved so exciting that the work was reported and, when accepted for publication, was recognized by the reviewers as the first contribution of its kind, with potential impact on the science.

Better optional experiments are kept on file for possible use to supplement current research or encourage students in further studies.

Parameters of a Pot Experiment

A team study in Soil Analytical Chemistry is detailed here:

Nearly every scientific investigation dealing with growing plants involves some sort of pot study, but a general lack of knowledge of basic principles in designing a pot experiment is frequently apparent. A search of the literature reveals little information regarding the pot parameters most desirable for satisfactory plant growth. This study was conducted to examine a few of these parameters.

The material which follows includes excerpts from reports submitted by participating students. They examined pot dimensions, watering methods, and methods of fertilization and their effects on the mineral composition and growth of oats and soybeans, and chemical changes in the soil.

The development of the growth chamber has made it possible to carry out growth studies under controlled conditions on a year round basis. For the results of such studies to be meaningful, it is neccessary to be able to apply them to field conditions. This requires an understanding of the effects of variables in temperature, humidity, photoperiod or various pot parameters. A gap exists in our understanding of the effects on growth by different pot designs or materials and methods of adding water and fertilizer, and the changes that may take place in the potted soil.

Pot Size and Pot Material

Plant growth in a given pot experiment would be affected by the evaporation of water, largely a factor of the surface area of the soil, and by the rooting volume, controlled by the volume of soil in the pot. Ideally, studies of the effect of pot size on plant growth would maintain a constant ratio of soil surface area to soil volume with planting based on a certain number of plants per unit of soil volume.

Cook and Millar, studying sugar beets, concluded that growth increased as pot size increased. Had they expressed growth as dry matter per plant per unit volume of soil, they would have noted that relative growth actually decreased with increasing pot size; a conclusion consistent with other reported data. Armiger *et al.* found, with some exceptions, that relative growth decreased as pot size increased. In their study, soil volume was ignored and plantings were based on surface area. Expressing their data as dry matter production per unit volume would have given more consistent comparisons. In a later study with millet, soil volume and not surface area was considered. Again relative growth was shown to decrease as pot size increased.

At the beginning of the study reported here, one student elected to examine the effect of pot shape on soybean growth. Although this experiment was not carried to completion as planned, dry matter production strongly suggested that growth was related to the amount of evaporative surface exposed to the atmosphere, and the results indicated that re-evaluation of pot shape for influence on plant growth is in order.

The wide variety of containers used for pots includes tin cans, crocks, fired clay, pressed peat and papier mache, glass and plastic-coated or wax-coated paper. Eastoe and Pollard reported that several researchers have noted deterioration of the nutrient status of soil when fired clay flower pots are used. This was considered at least partly due to the porous nature of the pot wall. McCall observed that plants in plastic pots lost one-third less water than those in clay pots.

Moisture Regime of Soil

The moisture regime of a soil is a major factor in determining the growth patterns of plants. At high moisture content, the exclusion of sufficient oxygen from the soil results in nutrient transformations which affect plant growth. Hopkins *et al.* reported that with the exception of magnesium, all the major elements (calcium, phosphorus, potassium) decreased in soybean tops when the oxygen content of the soil decreased. Accumulation of minor elements, except for iron and manganese, decreased when oxygen decreased.

In respect to nutrient interaction, Dekock *et al.* found phosphorus adversely affected by the iron level, while calcium increased with increased iron content Such results may be due in part to alteration of physical characteristics of the salts in solution, e. g. solubility. Increased potassium in the nutrient solution corresponded to an increase in the P/Fe ratio in the plant while increases in iron in solution corresponded to decreases in the K/Ca ratio.

Under waterlogged conditions some hydrogen acceptor other than molecular oxygen must be used by the anaerobes for respiration. If sulfates or nitrates are present, they will be used in preference to iron and manganese oxides as sources of molecular oxygen, according to Montomura. Under low sulfate and nitrate conditions, manganese will be reduced before iron. Manganese oxide will, in fact, oxidize Fe^{+2} to Fe^{+3} as indicated in the following equations:

$$Mn_2 + 4H^+ + 2e = Mn^{+2} + H_2O \qquad E^\circ = 1.23\ v\ (1)$$
$$Fe^{+3} + e = Fe^{+2} \qquad E^\circ = 0.72v\ (2)$$

These equations show that Mn^{+4} (as in MnO_2) has a much greater affinity for electrons than Fe^{+3}. Therefore, when other sources of electrons are limiting in the soil, Mn^{+4} will derive electrons from Fe^{+2}, oxidizing the iron to the ferric state.

Kliman postulated that ferric iron must be reduced to the ferrous form before being absorbed by the plant. In a somewhat similar study, Wain *et al.* suggested that manganic oxides must be reduced to Mn^{+2} at the root surface before they can be absorbed. Thus, manganese must be in the reduced form for appreciable plant accumulation to occur.

Cook and Millar, studying sugar beet yields, reported that subsurface watering through glass tubes had little or no advantage over surface watering. Others described continuous watering techniques. Either continuous watering or subsurface watering will result in some waterlogging of the soil. Plants in pots watered once daily from the surface may undergo severe fluctuations in moisture stress. Payne *et al.* employed a wick pot design with watering carried on as needed. They noted significant increases in the above ground dry weight of four flowering species and improvement in root condition from peat wick design pots as compared with conventional designs.

Addition of Fertilizer

Erickson and Wedding found that eight plant species grew better when fertilized at daily intervals than when the same amount of fertilizer was added at greater intervals. Cook and Millar noted that fertilizer placed at the surface was more effective in the growth of sugar beets than when mixed or added near the middle or bottom of the pot.

General Procedure

The soil chosen for the study was a Nicollet clay loam of pH 6.3, 7.6% organic matter, 39 meq/100 g cation exchange capacity, 0.45% total N, 128 ppm extractable phosphorus, 176 ppm exchangeable potassium, 1050 ppm total phosphorus, 11,160 ppm total potassium, and a field capacity (⅓ or 0.33 atmosphere tension) of 27.4 per cent water. Three hundred grams of the air-dried soil was weighed into a wax-coated one pint carton. Twenty oat (variety Lodi) seeds or 10 soybean (variety Chippewa 64) seeds were planted and covered with 100 g of soil. All seed had been pretreated with Captan fungicide to inhibit soil pathogens. Due to the chemical and physical alteration of soil by most sterilization methods as observed by both Adams and Clark, and the fact that they do not simulate field conditions, the soil was not sterilized. After emergence of the seedlings, pots were thinned to 10 oats or 5 soybeans per pot. All treatments were planted in triplicates.

The plants were grown in a growth chamber under conditions of 23 ± 3% relative humidity during 16 hours of light of 2,000 foot candles intensity at 70°F and 27 ± 5% relative humidity during 8 hours of darkness at 60°F.

Thirty-nine to 43 days after planting, the plants were harvested and dried for 48 hours at 70° C before recording dry weights and preparing for analyses. Plant materials were analyzed for nitrogen by microKjeldahl and mineral elements by emission spectrograph. Statistical analyses were performed by Experiment Station statisticians using analysis of variance.

Effect of Watering Methods on Mineral Composition and Dry Matter Yields

R. C. Leslie and W. A. Patterson

Four methods of watering were used:

1. Watering at the surface every 12 hours to 25 per cent moisture;
2. Watering at the surface every 24 hours to 30 per cent moisture;
3. Watering from the bottom with a peat wick;

4. Watering from the bottom by standing pots in a tray of water.

In Treatment 3, 100 ml of coarse, acid-washed silica sand was placed in the bottom of a wax-coated carton. Another carton containing the soil was set inside the first carton. The bottom of the soil container was perforated and a peat wick ¼ inch wide and 3 inches long was passed from the soil into the sand in the carton below. Water was added to the sand each day equivalent to 20 per cent moisture in the soil above. Pots in Treatment 3 were watered from the surface until emergence. In Treatment 4, pots were perforated with ten ¼ inch slits in the bottom and placed in a tray containing ½ inch of water at all times. The soil in the latter pots was continuously saturated with water.

Results and Discussion

Table 1 shows dry weight and mineral composition of tops. The wick used in Treatment 3 was not adequate to move water from the reservoir into the pot above. As a result, the plants grew under continuous moisture stress, with moisture conditions in this experiment ranging from droughty to water-saturated. There were no significant variations among replicates, but significant differences in species response were apparent. The watering methods significantly affected growth and accumulation of all mineral elements except Sr, Zn, and Mo. In oats the concentration of N, Ca, and Mn in the plant tops was greater in pots growing under droughty conditions as compared with the water-saturated conditions; while the concentration of P, K, Fe, and Zn in the plant tops and dry matter production was lower. In soybeans, the concentration of N, P, Mg, Fe, Mn, and Zn in plant tops was greater under droughty conditions. Only the concentration of K and Ca and dry matter was lower as a result of moisture stress.

Although dry matter production was greatest under water-saturated conditions, this was not the most desirable method of watering. Both oats and soybeans grown with this treatment exhibited severe chlorosis. The much lower nitrogen and iron content of the plant tops grown with this treatment indicated chlorosis was due to deficiencies of these elements. Twice daily watering appeared advantageous for soybeans and once daily was better for oats. Watering once a day would represent the maximum variation from near waterlogged to near droughty conditions in any one day.

Effects of Watering Methods and Nutrient Addition on Mineral Composition and Dry Matter Yield

CHIHNING SUN and L. L. OLSON

In this experiment, one half of the pots were watered from the surface. The other half were watered by the wick method used by Leslie and Patterson, except that a ¾-inch wick was used (¼ inch wider). Water was added to bring the soil to its weight at field capacity in all pots once daily. Forty milligrams each of N, P, and K were added to each pot in the forms of NH_4NO_3, $Ca(H_2PO_4)_2 \cdot H_2O$, and KC1, respectively. In half of the pots, fertilizer was mixed thoroughly into the soil at the beginning of the experiment. In the remaining half of the pots, fertilizer was added with the water in equal increments at four-day intervals. A factorial combination of top and wick watering and addition of nutrients at the start or during the experiment gave four triplicated treatments for each plant species.

Results and Discussion

Table 2 shows dry matter production, emission spectrograph analyses and statistical analysis. Moisture conditions were satisfactory with both watering techniques and there were no significant variations among replicates. Watering methods significantly affected the uptake of every nutrient but phosphorus. A marked difference in response between species occurred. The concentration of all minerals, except phosphorus and manganese, was reduced by subirrigation. However, with soybeans total

TABLE 1. Dry matter production and mineral composition of tops of oats and soybeans when watered by four different methods. Average of triplicates.

Treatments	Dry Matter	N	P	K	Ca	Mg	Sr	Fe	Mn	Zn	Mo	B
	g	%					ppm					
Oats												
Surface watered every 12 hrs.	0.53	1.50	0.68	2.55	0.72	0.45	15	30	41	15	0.8	17
Surface watered every 24 hrs.	0.90	1.24	0.55	2.16	0.44	0.27	9	23	33	13	0.6	11
Subirrigated by wick	0.35	1.02	0.29	0.97	0.42	0.23	4	10	43	8	0.4	9
Subirrigated, continuously	1.35	0.67	0.62	2.25	0.37	0.24	3	16	29	15	0.4	9
Soybeans												
Surface watered every 12 hrs.	1.21	3.32	0.45	1.13	1.09	0.59	28	71	32	30	1.2	51
Surface watered every 24 hrs.	1.17	3.15	0.41	0.94	1.27	0.66	36	61	32	25	1.0	53
Subirrigated by wick	0.78	3.41	0.40	0.93	0.84	0.47	20	72	39	27	1.1	37
Subirrigated continuously	3.83	2.13	0.37	0.98	1.21	0.45	25	40	25	18	1.1	37
Statistical analysis												
Species	**	**	*	**	**	***	**	***	N.S.	**	**	***
Watering	***	***	***	***	***	***	*	***	***	**	N.S.	***
Watering x Species	**	*	***	***	***	**	N.S.	**	N.S.	***	N.S.	**

N.S. = not significant * = F value significant at 10 per cent level ** = F value significant at 5 per cent level
*** = F value significant at one per cent level.

TABLE 2. Dry matter production and mineral composition of tops of oats and soybeans when watered by two methods and fertilized by two methods. Average of triplicates.

Treatments	Dry Matter	N	P	K	Ca	Mg	Sr	Fe	Mn	Zn	Mo	B
	g	%					ppm					
Oats												
Surface watered												
Fertilizer mixed	1.96	1.31	0.64	2.29	0.62	0.28	13	68	28	28	1.5	14
Fertilizer in increments	1.53	1.84	0.62	2.78	0.76	0.39	17	48	28	16	1.8	17
Subirrigated												
Fertilizer mixed	2.16	0.80	0.41	1.45	0.37	0.20	7	22	72	13	1.4	16
Fertilizer in increments	2.78	1.28	0.79	2.06	0.33	0.18	3	21	53	13	1.3	9
Soybeans												
Surface watered												
Fertilizer mixed	1.09	4.01	0.55	1.68	1.44	0.55	38	66	36	23	2.3	50
Fertilizer in increments	1.33	3.58	0.47	1.24	1.58	0.67	46	64	32	22	2.3	80
Subirrigated												
Fertilizer mixed	2.36	1.91	0.34	0.61	1.08	0.50	28	41	49	16	1.9	56
Fertilizer in increments	2.73	2.03	0.52	0.95	0.90	0.33	21	30	39	20	1.4	41
Statistical analysis												
Species	N.S.	***	**	**	***	***	***	**	N.S.	*	N.S.	**
Watering	***	***	N.S.	***	***	***	***	***	***	***	***	**
Species x Watering	*	**	N.S.	N.S.	**	*	**	N.S.	***	N.S.	**	*
Fertilizer method	N.S.	N.S.	***	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Species x Fertilizer method	N.S.	**	***	***	N.S.	*	N.S.	N.S.	N.S.	N.S.	***	N.S.
Watering x Fertilizer method	N.S.	N.S.	***	**	**	***	***	N.S.	N.S.	N.S.	***	*
Species x Fertilizer x Watering	N.S.	N.S.	**	*	N.S.	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

N.S. = not significant * = F value significant at 10 per cent level ** = F value significant at 5 per cent level
*** = F value significant at one per cent level.

accumulation of the major cations was increased by subirrigation.

Subirrigation consistently increased dry matter production by both species as compared with surface watering. Mixing nutrients with the soil at the beginning of the experiment gave no significant differences in growth when compared with fertilization at intervals. However, the latter method produced a significantly greater phosphorus concentration in both species and greater potassium concentration in oats.

Some chlorosis appeared in the plants grown with subirrigation, probably because of the lower concentration of nitrogen and reduced availability of iron. The total nitrogen content (growth x per cent N) of the plants was not affected by watering techniques. With subirrigation, however, plants showed significantly more nitrogen accumulation when fertilizer was applied in small increments with the water for both oats (30.7 vs 17.2 mg) and soybeans (55.6 vs 43.9 mg). Similarly, oats absorbed much more phosphorus with subirrigation when phosphorus was added at intervals (19.3 mg) compared with mixing fertilizer with the soil initially (9.2 mg). In soybeans total accumulations were 13.2 and 8.1 mg respectively.

One of the major problems arising from surface irrigation in pot experiments is the consequent poor physical condition of the soil, which may result in reduced root respiration, as Harris and van Bavel have noted; in the accumulation of phytotoxic compounds in plants or soil, as discussed by Kramer; and disrupted water and nutrient adsorption by plant roots, which Brouwer has observed. According to Gunary and Larsen, subirrigation with occasional overhead watering will provide a more suitable moisture regime.

Efficiency of Nutrient Removal from Soil by Oats and Soybeans

J. E. BARBER and C. HWANG

Soil in the treatments watered once daily and by continuous subirrigation (by Leslie and Patterson) and the surface watered treatments (by Sun and Olson) was examined for changes in nutrient status. Total soil phosphorus and potassium were determined according to Olsen and Dean, and Pratt respectively. Extractable phosphorus and exchangeable potassium were determined according to Grava. Using Allison's ideas, total organic carbon was determined by subtracting carbonate carbon (acid-neutralization) from total carbon measured by dry combustion on a carbon analyzer. Ammonium nitrogen was determined in soils and roots by microKjeldahl as described by Bremner. An attempt was made to extract roots from the soil which were analyzed by emission spectrography.

Results and Discussion

Total soil phosphorus and potassium were determined but are not reported. Due to a large dilution factor, variability of replications in total analyses was greater than plant usage of any macronutrient. Consequently, a complete balance sheet would have no meaning. Table 3 gives results of the other analyses.

Attempts to attain complete separation of the plant roots from the soil by manual means were unsuccessful. As a result, the carbon and nitrogen contents of the soil remaining in the pots at the conclusion of these experiments were confounded by these residues. Air-illutriation might successfully remove roots in future experiments. With most treatments, the carbon content of the soil increased. The increase in carbon was too great to be accounted for solely by unrecovered roots and was considered due to undecomposed seed fragments remaining in the soil. In calculating soil C/N ratios, the measured values were adjusted assuming a C/N value for undecomposed roots and seed fragments of 30/1 and assuming all increases in carbon due to these sources. Soil C/N ratios uniformly increased during the course of the experiments.

In all treatments considerable ammonium-nitrogen was not recovered. Two factors may have contributed to this loss. High moisture content and low oxygen content favors biological denitrification. Roots in this small volume of soil would be expected to exhaust soil oxygen. Even with daily surface watering, there are alternate periods of waterlogging. Consequently, conditions were favorable for denitrification. In addition, the micro-Kjeldahl procedure used in this study did not include reduction of nitrite–or nitrate–forms to ammonium-nitrogen. As a result, any conversion of organic-nitrogen to oxidized nitrogen would not have been detected. However, denitrification seems a more probable reason for the failure to account for considerable nitrogen.

Phosphorus is a relatively immobile nutrient. Favorable conditions can result in the conversion of fixed forms of phosphorus to available forms. Increased acidity or reducing conditions may make phosphorus more available. Subirrigation and waterlogging would contribute to the latter. Active denitrification processes would increase acidity. Soil pH changes were not measured in this study, however. In the watering experiments the sum of plant usage and the extractable phosphorus was greater than the extractable phosphorus found in the stock soil. One must bear in mind that extractable phosphorus is only an estimate of availability; a measure having more correlative value than quantitative value. However, the conversion of fixed phosphorus to extractable phosphorus was particularly evident in the water-saturated treatment.

In the fertilized pots, plant use plus extractable phosphorus in no case equaled the extractable phosphorus in the stock soil plus fertilizer phosphorus. However, where phosphorus was added at regular intervals, rather than initially, extractable phosphorus, and presumably plant available phosphorus, was much higher. This was not reflected in plant accumulation with surface watering.

The greater the amount of potassium added to a soil, the greater the amount that will be fixed. Chaminade found that pronounced potassium fixation resulted if more than 4 per cent of the cation exchange capacity was occupied by potassium. For the soil used in this study, 182 mg of potassium would be required to give 4 per cent of the exchange capacity. This value was not exceeded, and fixation might have been expected to be minimal. Cereal crops are heavy potassium users, and in both the watering and fertilizer experiments oats apparently were utilizing some fixed potassium (Exchangeable K + K in plants was greater than exchangeable K in stock soil + fertilizer K). On the other hand, with soybeans potassium fixation appeared to be occurring in all treatments. Soybeans appeared unlikely to be utilizing fixed potassium.

Soil Reduction by Electrical Current In Half of Pots

B. T. Bowman

The procedure used by Sun and Olson in mixing fertilizer with the soil initially was followed, except that one-half the pots were planted to soybeans and one-half were fallow controls. No wick was used in subirrigation, but the bottoms of pots were perforated with six 2-mm holes. An electrical current of about one milliamp and 150 v DC was passed through the soil with an AC-DC rectifier in one-half the pots (pots connected in series) of each set. Current was not applied to the soil until soybeans reached 2 to 3 cm in height. The application of current was stopped about 10 minutes each day during the watering period.

Immediately after harvesting (40 days), samples of soil in each pot were taken to extract exchangeable ferrous iron, followed by extractions for exchangeable ferric iron (includes ferrous), easily reducible manganese and exchangeable manganese, according to procedures described by Jackson. Iron and manganese content of the

Table 3. Analyses of soil carbon and soil and plant nitrogen, phosphorus, and potassium in four pot treatments. Average of triplicates.

Treatments	Soil C	N Added	N Soil (NH_4^+)	N Plant	Soil C/N	P Added	P Soil (Extract)	P Plant	Added	Soil (Exchange)	Plant
	g/pot	mg/pot	mg/pot	mg/pot		mg/pot	mg/pot	mg/pot	mg/pot	mg/pot	mg/pot
Stock soil	19.6*†	0	1800†	..	10.9*†	0	48†	..	0	60†	..
Oats, surface watered	21.8	0	1448	14	13.9	0	45	6	0	58	18
Oats, subirrigated	21.4	0	1364	18	15.0	0	51	4	0	40	41
Soybeans, surface watered	21.9	0	1372	46	15.1	0	45	5	0	36	14
Soybeans, subirrigated	23.4	0	1416	88	15.1	0	49	4	0	39	16
Oats, fertilizer mixed	19.9	40	1440	39	13.7	40	36	13	40	59	47
Oats, fertilizer increments	20.6	40	1484	30	13.5	40	65	10	40	57	42
Soybeans, fertilizer mixed	19.2	40	1480	55	13.1	40	44	7	40	49	18
Soybeans, fertilizer, increments	18.6	40	1488	107	12.9	40	53	7	40	55	35

* Excess carbon over stock soil attributed to roots or seed fragments. C/N ratio of this tissue assumed to be 30/1 and soil C/N ratios adjusted accordingly.

† Average of eight replications.

extracts was determined on a Perkin-Elmer 303 Atomic Absorption Spectrophotometer.

Results and Discussion

Producing reducing conditions in the soil by waterlogging or addition of chemicals has two disadvantages. Waterlogging the soil is detrimental to growth, and most chemicals when used at high concentrations would produce phytotoxic effects. Second, these reducing agents might not exert uniform effects over the entire period of growth. The use of direct current was advantageous since the electron was the only "reagent" involved, and uniform control was possible. No adverse effects on plant growth were noted. To enhance the effects of the direct current, moisture content was maintained at near field capacity. Table 4 shows results of soil analyses. In those pots receiving electricity, exchangeable manganese and exchangeable iron in the soil was significantly increased, confirming that reducing conditions were produced. Greater reduction of manganese and iron with the surface watered treatments was unexpectedly observed. This may have been caused by better contact with the electrodes and consequently better transmission of current through the soil. In subirrigated pots a layer of dry soil mulch near the surface of the pot was never wetted during the course of the experiment.

Perhaps a better indication of reducing conditions through subirrigation is the exchangeable ferrous iron. Ferrous iron very quickly oxidizes to ferric iron when exposed to air. Ferrous iron could be detected only in treatments subjected to an electrical current and subirrigated. With subirrigation some portion of the soil in the bottom of the pot would be continuously waterlogged. With surface watering, oxygen would permeate the surface of the soil and some would be driven downward by infiltrating water. As a result, the soil in surface-watered pots would be alternately aerated and waterlogged.

Summary

Individual students varied their procedures, although slightly, in ways that preclude valid comparisons of results. However, some generalizations may be made if ratios of elements are calculated. Reducing conditions were clearly produced by subirrigation, as reflected in the consistently smaller Fe/Mn ratios and greater P/Ca ratios in the plant material grown in subirrigated pots as compared with surface-watered pots. This is confirmed also by the high level of extractable phosphorus from the subirrigated pots. A general loss of soil nitrogen occurred and was presumed to be due to denitrification. Total growth and accumulation of major cations was greater with subirrigation, even though the concentration of the cation was reduced in the plant tissue. With subirrigation the relative ability of oats to feed on potassium declined while with soybeans it increased slightly. Apparently the oats were utilizing at least a portion of the fixed potassium in the soil whereas soybeans seemed to enhance fixation.

Whether subirrigation is desirable in pot experiments would appear to depend upon the objectives of the experiment. Reducing conditions resulting from subirrigation would affect mineral accumulation by the plants and increase the occurrence of chlorosis. These effects might be less desirable than the favorable increase in production of dry matter. Certainly subirrigation would change nutrient requirements, with additional nitrogen a particular necessity.

The method of fertilizing had no consistent effect. However, species x watering, species x fertilizer method, and species x watering x fertilizer method interactions were significant. This indicates that choice of both watering methods and fertilizing methods may be dependent upon the plant studied and should vary with the individual investigation.

The data reported here must be regarded in light of the fact that they were obtained in one attempt, for the most part, by students lacking experience in such analyses. It should be noted, however, that in no case was there a statistically significant difference among replications. The results clearly illustrate some basic principles that need to be considered in designing pot experiments.

In addition, several exciting possibilities for further study were raised. The simple question of pot shape e.g., needs real evaluation and effects on the availability of soil nutrients in pot experiments may be quite important. Furthermore, the fact that reduction can be accomplished by transmitting an electrical current through soil is an approach, which can have many applications

TABLE 4. Analyses of soils for iron and manganese. Average of triplicates.

Treatments	Dry Matter	Easily Reducible Mn	Exchangeable Mn	Exchangeable Ferric and Ferrous Fe	Exchangeable Ferrous Fe
	g /pot	PPM			
Fallow					
Current, surface watered	–	183	7.3	25.4	T*
No current, surface watered	–	159	1.4	N.D.†	N.D.
Current, subirrigated	–	173	3.8	31.1	9.3
No current, subirrigated	–	177	T	T	N.D.
Soybeans grown					
Current, surface watered	3.4	162	9.5	70.9	N.D.
No current surface watered	3.4	182	1.3	N.D.	N.D.
Current, subirrigated	3.5	171	8.7	18.6	5.6
No current, subirrigated	3.2	178	1.6	4.0	N.D.

*T = trace
†N.D. = none detectible

in studying such things as chlorosis and trace element utilization by plants. The author feels strongly that these experiments show that laboratory classes can be conducted in such a way as to obtain preliminary research data while the student learns laboratory techniques.

Reference

ADAMS, R. S., JR. 1966. Ethylene oxide sterilization alters soil characteristics. Soil Biol. Int. News Bul. No. 5, pp. 37-39.

ALLISON, L. E. and C. D. MOODIE. 1965. Carbonate, in *Methods of Soil Analysis,* Agronomy Monograph No. 9. Amer. Soc. Agronomy, Madison, Wisc. 1379-96.

ARMIGER, W. H.; L. A. DEAN; D. D. MASON, and E. J. KOCH. 1958. Effect of size and type of pot on relative precision, yields, and nutrient uptake in greenhouse fertilizer experiments. Agron. J. 50: 244-47. 1958.

ARMIGER, W. H. and M. FRIED. 1958. Effect of pot size and shape on yield and phosphorus uptake of millet. Agron. J. 50: 462-65.

BREMNER, J. M. 1965. Total nitrogen, in Methods of Soil Analysis, Agronomy Monograph No. 9. Amer. Soc. Agronomy, Madison, Wisc., pp. 1149-78.

BROUWER, R. 1965. Ion adsorption and transport in plants. Ann. Rev. Plant Physiol. 16: 241-66.

CHAMINADE, R. 1936. Surle passage a l'etat non exchangeable du potassium dans les sols. Compt. Rend. 203: 682-84.

CLARK, F. E. 1950. Changes induced in soil by ethylene oxide sterilization. Soil Sci. 70: 345-49.

COOK, R. L. and C. E. MILLAR. 1946. Some techniques which help to make greenhouse investigations comparable with field plot experiments. Soil Sci. Soc. of Amer. Proc. N:298-304.

DEKOCK, P. C.; A. HALL, and M. MCDONNEL. 1960. A relation between ratios of phosphorus to iron and potassium to calcium in mustard leaves. Plant and Soil 12: 128-42.

EASTOE, J. E. and A. G. POLLARD. 1959. Some effects of the flowerpot on plant growth. Plant and Soil 11: 331-42.

ERICKSON, L. C. and R. T. WEDDING, 1958. Frequency of Mineral Application to Five Media in the Greenhouse Production of Plants. Proc. Amer. Soc. Hort. Sci. 71:485-95.

GRAVA, J. 1962. Soil Analysis Methods as Used in the University of Minnesota Soil Testing Laboratory. Form 15-G (Rev. 1).

GUNARY, D. and S. LARSEN. 1966. The influence of method of watering on phosphate uptake by ryegrass grown in pots: effect on the L-value. Plant and Soil 24: 351-58.

HARRIS, D. G. and C. H. M. VAN BAVEL. 1957. Root respiration of tobacco, corn and cotton plants. Agron. J. 49: 182-84.

HOPKINS, H. T.; A. W. SPECHT, and S. B. HENDRICKS. 1950. Growth and nutrient accumulation as controlled by oxygen supply to plant roots. Plant Physiol. 25: 193-209.

JACKSON, M. L. 1958. Soil Chemical Analysis, Prentice-Hall, Inc., Englewood Cliffs, N. J.

KLIMAN, S. 1937. The importance of ferrous iron in plants and soils. Soil Sci. Soc. Amer. Proc. 2: 385-92.

KRAMER, P. J. 1951. Causes of injury to plants resulting from flooding of the soil. Plant Physiol. 26: 722-36.

MCCALL, W. W. 1959. Moisture studies with greenhouse soils. Michigan Agric. Expt. Sta. Quart. Bul. 42: 35-42.

MONTOMURA, S. 1962. The relationship between ferrous iron formation and nitrogen metabolism in soil. Soil Sci. and Plant Nutrit. 8: 177-85.

OLSEN, S. R. and L. A. DEAN. 1965. Phosphorus in *Methods of Soil Analysis* Agronomy Monograph No. 9. Amer. Soc. Agron, Madison, Wisc., pp. 1035-49.

PAYNE, R. N., J. D. TRIPLETT, S. C. WIGGANS, and D. G. WHITE. 1962. The use of wicks for watering and fertilizing potted plants. Oklahoma State Univ. Expt. Sta., Processed Series P-400: 1-39.

PRATT, P. F. 1965. *Potassium in Methods of Soil Analysis,* Agronomy Monograph No. 9. Amer. Soc. Agron. Madison, Wisc., pp. 1022-30.

TURNER, M. A. and R. S. ADAMS, JR. 1968. The adsorption of atrazine and atratone by anion and cation exchange resins. Soil Sci. Soc. Amer. Proc. 32: 62-63.

WAIN, R. L., B. J. SILK, and B. C. WILLS. 1943. The fate of manganese sulphate in alkaline soils. J. Agric. Sci. 33: 18-22.